

## SECTION 17 - SOIL REINFORCED CONCRETE STRUCTURE INTERACTION SYSTEMS

### 17.1 GENERAL

#### 17.1.1 Scope

Specifications in this section govern the design of buried reinforced concrete structures. A buried reinforced concrete element becomes part of a composite system comprising the reinforced concrete section and the soil envelope, both of which contribute to the structural behavior of the system.

#### 17.1.2 Notations

<p>A = effective tension area, in square inches, of concrete surrounding the flexural tension reinforcement and having the same centroid as that reinforcement, divided by the number of bars or wires. When the flexural reinforcement consists of several bar sizes or wire sizes, the number of bars or wires shall be computed as the total area of reinforcement divided by the area of the largest bar or wire used. (Articles 17.6.4 and 17.7.4)</p>	<p>point of maximum moment for quadrant mat reinforcement, in.<sup>2</sup> (Article 17.4.7)</p>
<p>A<sub>P</sub> = total active lateral pressure acting on pipe, lbs/ft (Figure 17.4G)</p>	<p>b = width of section which resists M, N, V— Usually b = 12 inches (Article 17.4.6)</p>
<p>A<sub>s</sub> = tension reinforcement area on width b, in.<sup>2</sup>/ft. (Articles 17.4.6.6, 17.6.4.7, 17.7.4.7 and 17.8.5.7)</p>	<p>B<sub>c</sub> = out-to-out horizontal span of pipe, or box, ft (Articles 17.4.4 and 17.4.5)</p>
<p>A<sub>si</sub> = total area of inner cage reinforcement required in length b, in.<sup>2</sup>/ft (Article 17.4.6.6)</p>	<p>B<sub>f</sub> = bedding factor (Article 17.4.5)</p>
<p>A<sub>so</sub> = total area of outer cage reinforcement required in length b, in.<sup>2</sup>/ft (Article 17.4.6.6)</p>	<p>B<sub>fe</sub> = earth load bedding factor</p>
<p>A<sub>vr</sub> = stirrup reinforcement area to resist radial tension forces on width b, in.<sup>2</sup>/ft. in each line of stirrups at circumferential spacing s (Article 17.4.6.6.1)</p>	<p>B<sub>ILL</sub> = live load bedding factor</p>
<p>A<sub>vs</sub> = required area of stirrups for shear reinforcement, in.<sup>2</sup> (Article 17.4.6.6.2)</p>	<p>B<sub>1</sub> = crack control coefficient for effect of cover and spacing of reinforcement (Article 17.4.6)</p>
<p>A<sub>wa</sub> = actual steel area of the individual circumferential wire, in.<sup>2</sup> (Article 17.4.7)</p>	<p>B'<sub>c</sub> = out-to-out vertical rise of pipe, ft (Figure 17.4G)</p>
<p>A<sub>wr</sub> = steel area required for an individual circumferential wire for flexure at a splice or at the</p>	<p>C<sub>A</sub> = constant corresponding to the shape of pipe (Article 17.4.5)</p>
	<p>C<sub>N</sub> = parameter which is a function of the distribution of the vertical load and the vertical reaction (Article 17.4.5)</p>
	<p>C<sub>1</sub> = crack control coefficient for type of reinforcement (Article 17.4.6)</p>
	<p>d = distance from compression face to centroid of tension reinforcement, in. (Articles 17.4.6.6, 17.6.4.7, 17.7.4.7 and 17.8.5.7)</p>
	<p>d<sub>b</sub> = diameter of reinforcing wire or bar, in. (Article 17.4.7)</p>
	<p>d<sub>c</sub> = thickness of concrete cover measured from extreme tension fiber to center of bar or wire located closest thereto (Articles 17.6.4 and 17.7.4)</p>
	<p>D = D-load of pipe, three-edge bearing test load expressed in pounds per linear foot per foot of span to produce a 0.01-inch crack (Article 17.4.5)</p>
	<p>D<sub>i</sub> = inside diameter of pipe, in.</p>
	<p>f<sub>s</sub> = maximum allowable service load stress in the reinforcing steel for crack control (Articles 17.6.4.7, 17.7.4.7 and 17.8.5.7)</p>
	<p>f<sub>ss</sub> = actual service load stress in reinforcing steel (Articles 17.6.4.7, 17.7.4.7 and 17.8.5.7)</p>
	<p>f<sub>v</sub> = maximum allowable strength of stirrup material, lbs./in.<sup>2</sup> (Article 17.4.6.6.6)</p>
	<p>f<sub>y</sub> = specified yield strength of reinforcement, lbs./in.<sup>2</sup> (Article 17.4.6)</p>

$F_c$	= factor for effect of curvature on diagonal tension (shear) strength in curved components (Article 17.4.6.6.5)		
$F_{cr}$	= factor for adjusting crack control relative to average maximum crack width of 0.01 inch when $F_{cr} = 1.0$ (Article 17.4.6.6.4)		
$F_d$	= factor for crack depth effect resulting in increase in diagonal tension (shear) strength with decreasing $d$ (Article 17.4.6.6.5)		
$F_e$	= soil-structure interaction factor (Article 17.4.4)		
$F_{tp}$	= factor for process and local materials that affect the radial tension strength of pipe (Article 17.4.6)		
$F_{rt}$	= factor for pipe size effect on radial tension strength (Article 17.4.6.6.3)		
$F_{vp}$	= factor for process and local materials that affect the shear strength of pipe (Article 17.4.6.6.5)		
$F_N$	= coefficient for effect of thrust on shear strength (Article 17.4.6.6.5)		
$f'_c$	= design compressive strength of concrete, lbs./in. <sup>2</sup> (Articles 17.4.6, 17.6.2, and 17.7.2)		
$h$	= overall thickness of member (wall thickness), in. (Articles 17.4.6.6, 17.6.4.7, 17.7.4.7 and 17.8.5.7)		
$H$	= height of fill above top of pipe, ft. (Articles 17.4.4 and 17.4.5)		
HAF	= horizontal arching factor (Figure 17.4A)		
$i$	= coefficient for effect of axial force at service load stress, $f_s$ (Articles 17.4.6.6.4, 17.6.4.7, 17.7.4.7 and 17.8.5.7)		
$j$	= coefficient for moment arm at service load stress, $f_s$ (Articles 17.4.6.6.4, 17.6.4.7, 17.7.4.7 and 17.8.5.7)		
$K$	= ratio of the active unit lateral soil pressure to unit vertical soil pressure - Rankine's coefficient of active earth pressure (Figure 17.4G)		
$L_d$	= development length of reinforcing wire or bar, in. (Article 17.4.7)		
$M_{nu}$	= factored moment acting on length $b$ as modified for effects of compressive or tensile thrust, in-lbs/ft (Article 17.4.6)		
$M_s$	= moment acting on cross section of width, $b$ , service load conditions, in.-lbs/ft (taken as absolute value in design equations, always +) (Articles 17.4.6.6.4, 17.6.4.7, 17.7.4.7 and 17.8.5.7)		
$M_u$	= factored moment acting on cross section of width $b$ , in.-lbs./ft. (Article 17.4.6.6)		
$n$	= number of layers of reinforcement in a cage-		
			1 or 2 (Article 17.4.6)
		$N_s$	= axial thrust acting on cross section of width $b$ , service load condition (+ when compressive, - when tensile) lbs./ft. (Articles 17.4.6.6.4, 17.6.4.7, 17.7.4.7 and 17.8.5.7))
		$N_u$	= factored axial thrust acting on cross section of width $b$ , lbs./ft. (Article 17.4.6)
		$p$	= projection ratio (Article 17.4.5.2)
		PL	= PL denotes the prism load (weight of the column of earth) over the pipe's outside diameter, lbs/ft
		$q$	= ratio of the total lateral pressure to the total vertical load (Article 17.4.5)
		$r_s$	= radius of the inside reinforcement, in. (Article 17.4.6.6.3.1)
		$s_v$	= circumferential spacing of stirrups, in. (Article 17.4.6.6.6)
		$s_\ell$	= spacing of circumferential reinforcement, in. (Articles 17.4.6.6.4 and 17.4.7)
		$S_i$	= internal horizontal span of pipe, in. (Articles 17.4.5 and 17.4.6)
		$t_b$	= clear cover over reinforcement, in. (Article 17.4.6)
		$V_b$	= basic shear strength of critical section, lbs./ft. where $M_{nu}/V_u d = 3.0$ (Article 17.4.6.6.5)
		$V_c$	= nominal shear strength provided by width $b$ , of concrete cross section, lbs./ft. (Article 17.4.6)
		$V_u$	= factored shear force acting on cross section of width $b$ , lbs./ft. (Article 17.4.6)
		$V_{uc}$	= factored shear force at critical section, lbs./ft. where $M_{nu}/V_u d = 3.0$ (Article 17.4.6.6.5)
		VAF	= vertical arching factor (Article 17.4.4.2.1.1)
		$w$	= unit weight of soil, lbs per cubic foot (Article 17.4.4)
		$W_E$	= total earth load on pipe or box, lbs/ft (Articles 17.4.4 and 17.4.5)
		$W_f$	= fluid load in the pipe as determined according to Article 17.4.4.2.2, lbs/ft
		$W_L$	= total live load on pipe or box, lbs/ft (Articles 17.4.4 and 17.4.5)
		$W_T$	= total load, earth and live, on pipe or box, lbs/ft (Article 17.4.4 and 17.4.5)
		$x$	= parameter which is a function of the area of the vertical projection of the pipe over which lateral pressure is effective (Article 17.4.5)
		$\Psi$	= central angle of pipe subtended by assumed distribution of external reactive force (Figure 17.4F)
		$r$	= ratio of reinforcement area to concrete area (Article 17.4.6)

- $f_f$  = strength reduction factor for flexure (Articles 17.4.6.3 and 17.4.6.6)
- $f_r$  = strength reduction factor for radial tension (Article 17.4.6.3 and 17.4.6.6)
- $f_v$  = strength reduction factor for shear (Article 17.4.6.3 and 17.4.6.6)

### 17.1.3 Loads

- + Design loads shall be determined by the forces acting on the structure. For earth loads and live loads, see Section 6. For loading combinations see Article 3.22.

### 17.1.4 Design

- + Design shall be based on ultimate strength principles. The design criteria shall include structural aspects (e.g. flexure, thrust, shear), handling and installation, and crack control. Footing design for cast-in-place boxes and arches shall be in conformity with Article 4.4.

### + 17.1.5 Deleted

### 17.1.6 Soil

Structural performance is dependent on soil structure interaction. The type and anticipated behavior of the material beneath the structure, adjacent to the structure, and over the structure must be considered.

### 17.1.7 Abrasive or Corrosive Conditions

Where abrasive or corrosive conditions exist, suitable protective measures shall be considered.

### 17.1.8 End Structures

Structures may require special consideration where erosion may occur. Skewed alignment may require special end wall designs.

### + 17.1.9 Deleted

## 17.2 SERVICE LOAD DESIGN

- + Service load design shall not be permitted for the
- + design of reinforced concrete culvert structures. Service
- + load stresses may be used for crack control only.

## 17.3 LOAD FACTOR DESIGN

**17.3.1** Soil-reinforced concrete structure interaction systems shall be designed to have design strengths of all sections at least equal to the required strengths calculated for the factored loads as stipulated in Article 3.22, except as modified herein.

**17.3.2** For precast reinforced concrete circular pipe, elliptical pipe, and arch pipe, the results of three-edge-bearing tests may be used in lieu of load factor design.

## 17.4 REINFORCED CONCRETE PIPE

### 17.4.1 Application

This Specification is intended for use in design for precast reinforced concrete circular pipe, elliptical pipe, and arch pipe. Standard dimensions are shown in AASHTO Material Specifications M 170, M 206, M 207, and M 242. Design wall thicknesses other than the standard wall dimensions may be used, provided the design complies with all applicable requirements of Section 17.

### 17.4.2 Materials

#### 17.4.2.1 Concrete

Concrete shall conform to Article 8.2 except that evaluation of  $f'_c$  may be based on cores.

#### 17.4.2.2 Reinforcement

Reinforcement shall meet the requirements of Articles 8.3.1 through 8.3.3 only, and shall conform to one of the following AASHTO Material Specifications: M 31, M 32, M 55, M 221 or M 255. For smooth wire and smooth welded wire fabric, a yield stress of 65,000 psi and for deformed welded wire fabric, a yield stress of 70,000 psi may be used.

#### 17.4.2.3 Concrete Cover for Reinforcement

The minimum concrete cover for reinforcement in precast concrete pipe shall be 1 inch in pipe having a wall thickness of 2 ½ inches or greater and ¾ inch in pipe having a wall thickness of less than 2 ½ inches.

### 17.4.3 Installations

#### 17.4.3.1 Standard Installations

Standard Embankment Installations are presented in Figure 17.4B and Standard Trench Installations are presented in Figure 17.4C; these figures define soil areas and critical dimensions. Soil types, minimum compaction requirements, and minimum bedding thicknesses are listed in Table 17.4A for three Standard Embankment and Trench Installation Types.

#### 17.4.3.2 Deleted

### 17.4.4 Design

#### 17.4.4.1 General Requirements

Design shall conform to applicable sections of these specifications except as provided otherwise in this Section. For design loads, see Article 17.1.3; for standard installations, see Article 17.4.3.1. Live loads,  $W_L$ , shall be included as part of the total load,  $W_T$ , and shall be distributed through the earth cover as specified in Article 6.5. Other methods for determining total load and pressure distribution may be used, if they are based on successful design practice or tests that reflect the appropriate design conditions.

**TABLE 17.4A Standard Embankment and Trench Installation Soils and Minimum Compaction Requirements**

Installation Type	Haunch and Outer Bedding
Type 1	90% RC Str. Bkfl w/min SE = 30 and max % passing No 200 (75 $\mu$ m) shall be 12
Type 2	90% RC Str. Bkfl w/min SE = 25
Type 3	90% RC Str. Bkfl or 85% RC Str. Bkfl w/min SE = 25

#### EMBANKMENT NOTES:

- The bedding thickness shall be  $B_c/24$ " minimum but not less than 3". If an unyielding material is encountered at the planned elevation of the bedding, it shall be removed to a depth of  $H/50$  but in no case less than 6" nor more than 12". The resulting trench below the bottom of the bedding shall be backfilled with Structure Backfill and compacted.

- The Lower Side shall be suitable material as determined by the engineer. See Construction Manual.
- Soil in the outer bedding, haunch and lower side zones except for installation Type 3 shall be compacted to at least the same compaction as the majority of soil in the over fill zone.
- Only Type 2 and 3 installations are available for horizontal elliptical, vertical elliptical and arch pipe.
- SUBTRENCHES
  - A subtrench is defined as a trench with its top below finished grade by more than 0.1H or, for roadways, its top is at an elevation lower than 1' (0.3 m) below the bottom of the pavement base material.
  - For subtrenches with walls of natural soil, any portion of the lower side zone in the subtrench wall shall be at least as firm as an equivalent soil placed to the compaction requirements specified for the lower side zone and as firm as the majority of soil in the overfill zone, or shall be removed and replaced with soil compacted to the specified level. See Construction Manual.

#### TRENCH NOTES:

- The bedding thickness shall be  $B_c/24$ " minimum but not less than 3". If an unyielding material is encountered at the planned elevation of the bedding, it shall be removed to a depth of  $H/50$  but in no case less than 6" nor more than 12". The resulting trench below the bottom of the bedding shall be backfilled with Structure Backfill and compacted.
- The Lower Side shall be suitable material as determined by the engineer. See Construction Manual.
- The trench top elevation shall be no lower than 0.1H below finished grade or, for roadways, its top shall be no lower than an elevation of 1' (0.3 m) below the bottom of the pavement base material.
- Only Type 2 and 3 installations are available for horizontal elliptical, vertical elliptical and arch pipe.
- Soil in the outer bedding, haunch and lower side zones except for installation Type 3 shall be compacted to at least the same compaction as the majority of soil in the over fill zone.
- The trench width shall be wider than shown if required for adequate space to attain the specified compaction in the haunch and bedding zones.
- For trench walls that are within 10 degrees of vertical, the compaction or firmness of the soil in the trench walls and lower side zone need not be considered.
- For trench walls with greater than 10-degree slopes that consist of embankment, the lower side shall be compacted to at least the same compaction as specified for the soil in the backfill zone.

## 17.4.4.2 Loads

### 17.4.4.2.1 Earth Loads and Pressure Distribution

The effects of soil-structure interaction shall be taken into account and shall be based on the design earth cover, sidefill compaction, and bedding characteristics of the pipe soil installations.

#### 17.4.4.2.1.1 Standard Installations

For the Standard Installations given in 17.4.3.1, the earth load,  $W_E$ , may be determined by multiplying the prism load (weight of the column of earth) over the pipes outside diameter by the soil-structure interaction factor,  $F_e$ , for the specified installation type.

$$W_E = F_e w B_c H \quad (17-1)$$

Standard Installations for both embankments and trenches shall be designed for positive projection, embankment loading conditions where  $F_e = \text{VAF}$  given, in Figure 17.4A for each Type of Standard Installation.

For Standard Installations the earth pressure distribution shall be the Heger pressure distribution shown in Figure 17.4A for each type of Standard Installation.

The unit weight of soil used to calculate earth load shall be the estimated unit weight for the soils specified for the pipe-soil installation and shall not be less than 110 lbs/cu. ft. (120 lbs/cu. ft for pipe designed by the indirect method)

#### 17.4.4.2.1.2 Non-Standard Installations

When nonstandard installations are used, the earth load on the structure shall be the prism load (PL). The unit weight of soil shall be 140 lbs/cu. ft. Pressure distribution

shall be determined by an appropriate soil-structure interaction analysis. See Figure 17.4F for suggested pressure distributions.

### 17.4.4.2.2 Pipe Fluid Weight

The weight of fluid,  $W_f$  in the pipe shall be considered in design based on a fluid weight of 62.4 lbs/ft<sup>3</sup>, unless otherwise specified. For Standard Installations, the fluid weight shall be supported by vertical earth pressure that is assumed to have the same distribution over the lower part of the pipe as given in figure 17.4A for earth load.

### 17.4.4.2.3 Live Loads

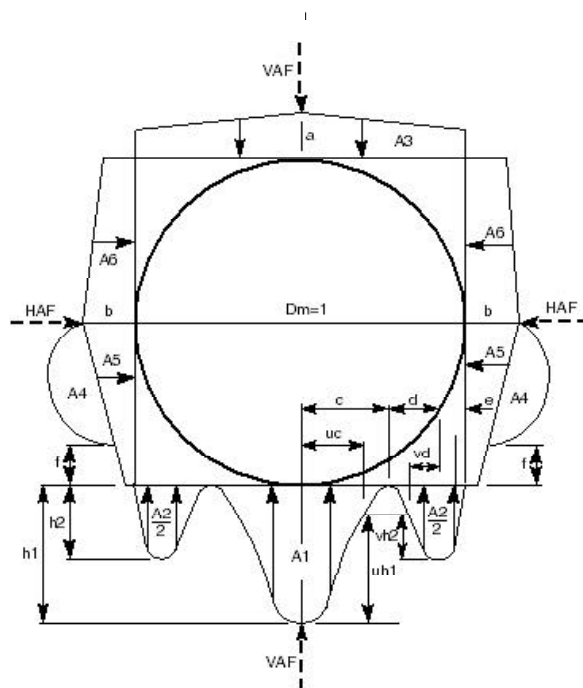
Live loads shall be the AASHTO HS – Series truck load. Live loads shall be distributed through the earth cover as specified in Article 6.5. For Standard Installations the live load on the pipe shall be assumed to have a uniform distribution across the top of the pipe and the same distribution across the bottom of the pipe as given in Figure 17.4A for earth load.

## 17.4.4.3 Minimum Fill

For unpaved areas and under flexible pavements the minimum fill over precast reinforced concrete pipes shall be two feet. For rigid pavements this distance shall be one foot.

## 17.4.4.4 Design Methods

The structural design requirements of installed precast reinforced concrete circular pipe for both standard and nonstandard installations may be determined by either the Indirect or Direct Method. Elliptical pipe in non-standard installations may be designed by either the indirect or direct method. Elliptical pipe in standard installations, and arch pipe regardless of installation type shall be designed by the indirect method.



Installation Type	VAF	HAF	A1	A2	A3	A4	A5	A6	a	b	c	e	f	u	v
1	1.35	0.45	0.62	0.73	1.35	0.19	0.08	0.18	1.40	0.40	0.18	0.08	0.05	0.80	0.80
2	1.40	0.40	0.85	0.55	1.40	0.15	0.08	0.17	1.45	0.40	0.19	0.10	0.05	0.82	0.70
3	1.40	0.37	1.05	0.35	1.40	0.10	0.10	0.17	1.45	0.36	0.20	0.12	0.05	0.85	0.60

#### Notes:

- VAF and HAF are vertical and horizontal arching factors. These coefficients represent nondimensional total vertical and horizontal loads on the pipe, respectively. The actual total vertical and horizontal loads are (VAF) X (PL) and (HAF) X (PL), respectively, where PL is the prism load.
- Coefficients A1 through A6 represent the integration of nondimensional vertical and horizontal components of soil pressure under the indicated portions of the component pressure diagrams (i.e., the area under the component pressure diagrams). The pressures are assumed to vary either parabolically or linearly, as shown, with the nondimensional magnitudes at governing points represented by  $h_1, h_2, u_{h1}, v_{h1}, a$  and  $b$ . Nondimensional horizontal and vertical dimensions of component pressure regions are defined by  $c, d, e, u, v$  and  $f$  coefficients.
- $d$  is calculated as  $(0.5 c - e)$   
 $h_1$  is calculated as  $(1.5 A_1) / (c) (1 + u)$   
 $h_2$  is calculated as  $(1.5 A_2) / [(d) (1 + v) + (2e)]$ .

**Figure 17.4A Heger Pressure Distribution and Arching Factors**

### Standard Embankment Installation

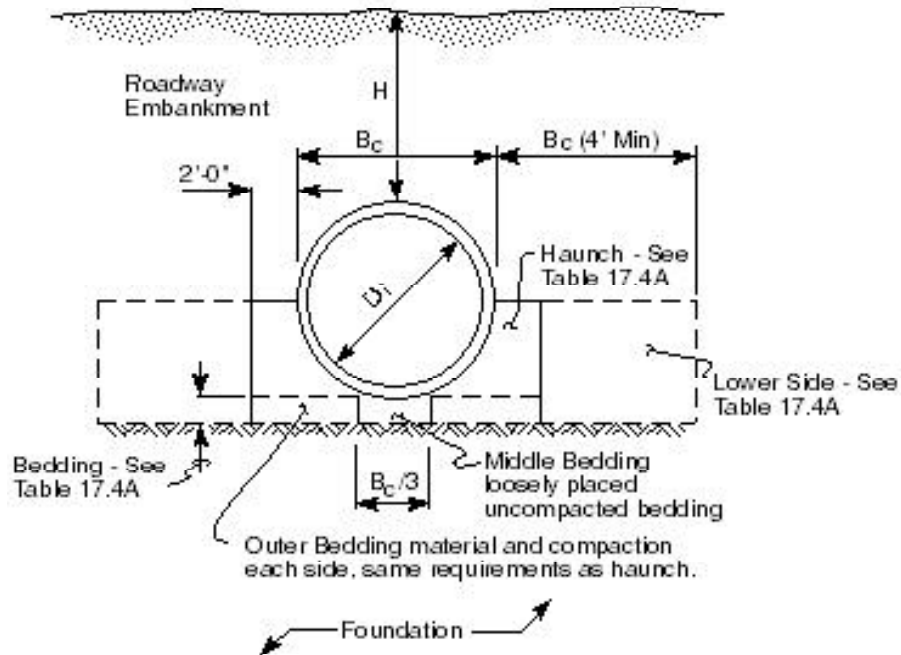


Figure 17.4B

### Standard Trench Installation

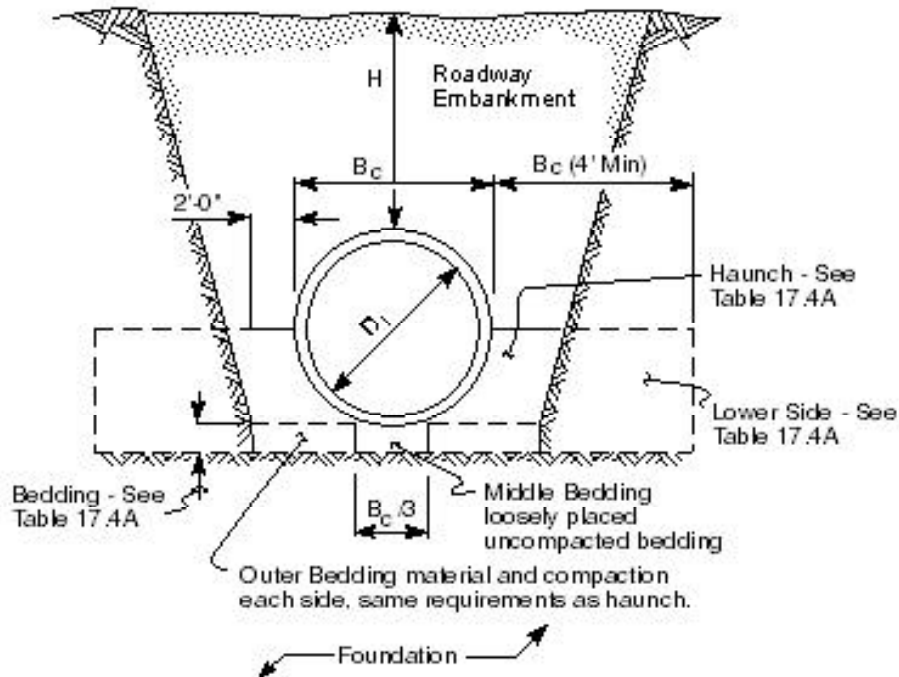


Figure 17.4C

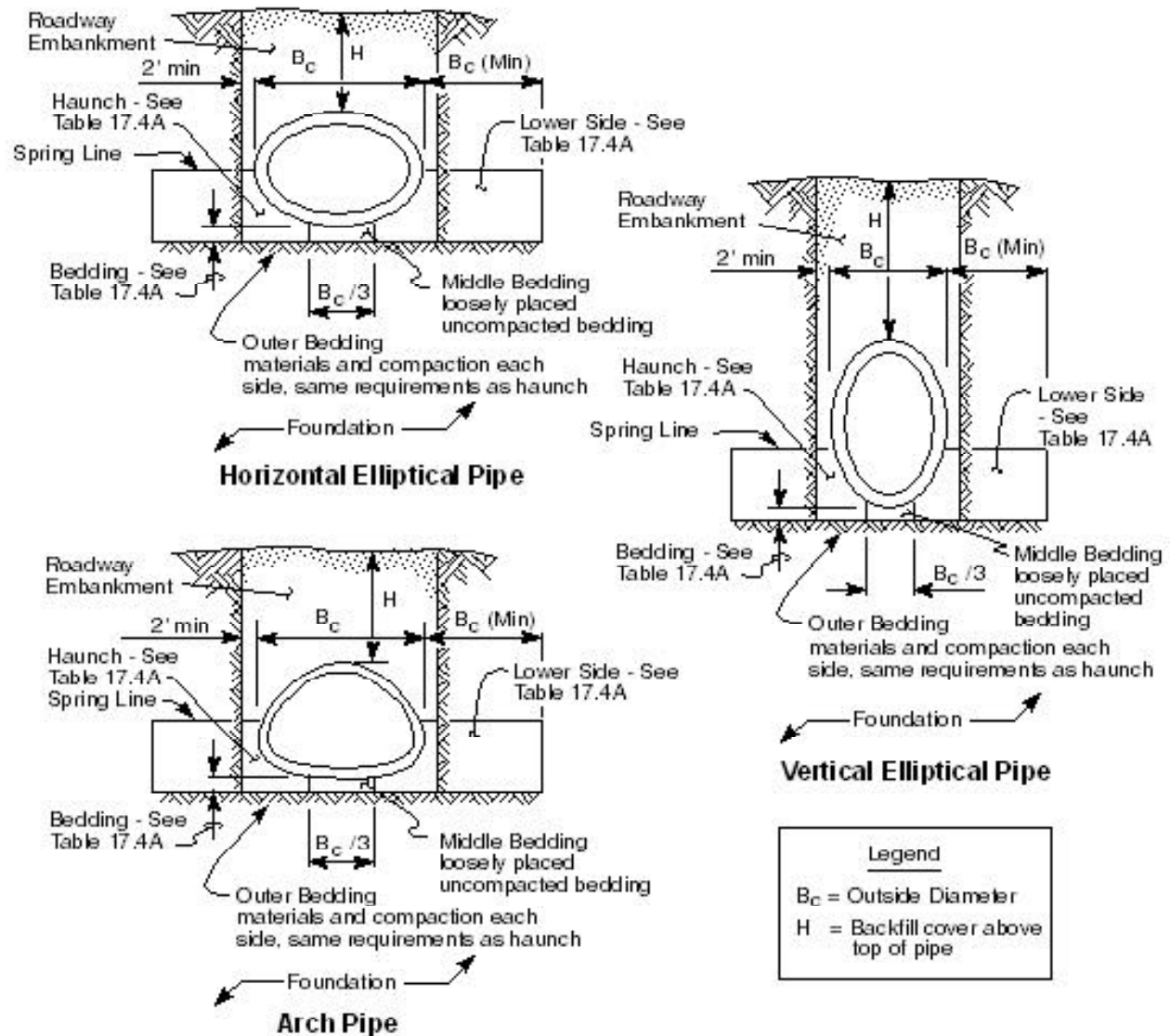


Figure 17.4D Trench Beddings, Miscellaneous Shapes



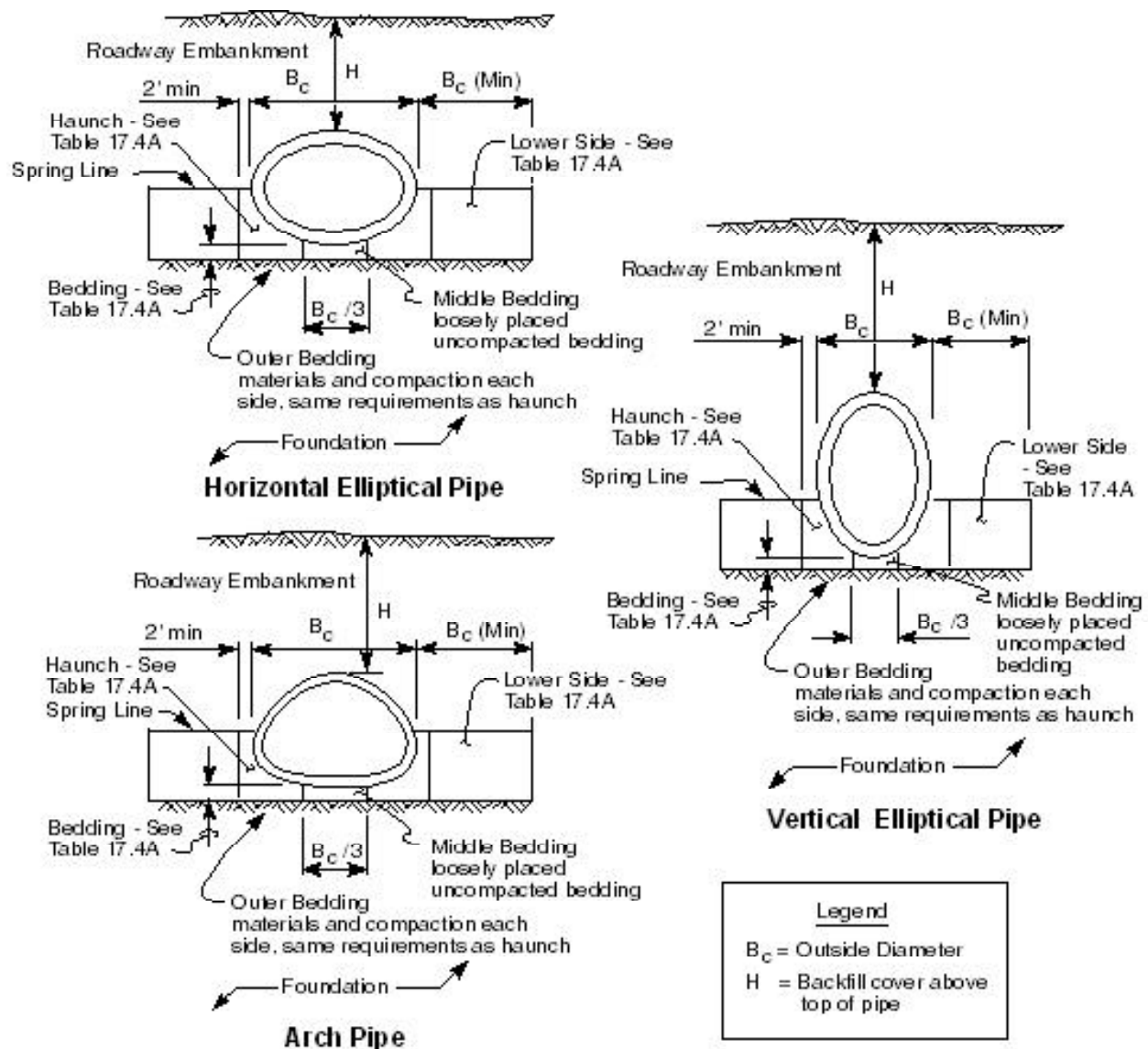


Figure 17.4E Embankment Beddings, Miscellaneous Shapes

### 17.4.5 Indirect Design Method Based on Pipe Strength and Load-Carrying Capacity

#### 17.4.5.1 Loads

The design load-carrying capacity of a reinforced concrete pipe must equal the design load determined for the pipe as installed, or

$$D = \left[ \frac{12}{S_i} \right] \left[ \frac{W_E + W_F}{B_{fe}} + \frac{W_L}{B_{LL}} \right] \quad (17-2)$$

where:

$D$  = D-load of the pipe (three-edge-bearing test load expressed in pounds per linear foot per foot of diameter) to produce a 0.01-inch crack. For Type 1 installations, D-load as calculated above shall be modified by multiplying by an installation factor of 1.10;

$S_i$  = internal diameter or horizontal span of the pipe in inches;

$B_f$  = bedding factor, See Article 17.4.5.2;

$B_{fe}$  = earth load bedding factor;

$B_{LL}$  = live load bedding factor;

$W_T$  =  $W_E + W_L$ ;

$W_T$  = total load on the pipe as determined according to Article 17.4.4;

$W_E$  = earth load on the pipe as determined according to Article 17.4.4;

$W_F$  = fluid load in the pipe as determined according to Article 17.4.4.2.2;

$W_L$  = live load on the pipe as determined according to Article 17.4.4.

**Table 17.4B Design Values of Parameters in Bedding Factor Equation**

Pipe Shape	Values of $C_A$	Type of Bedding	Values of $C_N$	Projection Ratio	Values of $x$
Horizontal Elliptical And Arch	1.337	Type 2	0.630	0.9	0.421
		Type 3	0.763	0.7	0.369
				0.5	0.268
Vertical Elliptical	1.021	Type 2	0.516	0.3	0.148
				0.9	0.718
		Type 3	0.615	0.7	0.639
				0.5	0.457
				0.3	0.238

**Table 17.4C Bedding Factors for Circular Pipe**

Standard Installations			
Pipe Diameter, in.	Type 1	Type 2	Type 3
12	4.4	3.2	2.5
24	4.2	3.0	2.4
36	4.0	2.9	2.3
72	3.8	2.8	2.2
144	3.6	2.8	2.2

Note:

- For pipe diameters other than listed, embankment condition bedding factors,  $B_{fe}$  can be obtained by interpolation.
- Bedding factors are based on soils being placed with the minimum compaction specified in Table 17.4A for each Standard Installation.

Table 17.4D Bedding Factors  $B_{fLL}$  for HS20 Live Loadings

Fill Height, Ft	Pipe Diameter, in.										
	12	24	36	48	60	72	84	96	108	120	144
0.5	2.2	1.7	1.4	1.3	1.3	1.1	1.1	1.1	1.1	1.1	1.1
1.0	2.2	2.2	1.7	1.5	1.4	1.3	1.3	1.3	1.1	1.1	1.1
1.5	2.2	2.2	2.1	1.8	1.5	1.4	1.4	1.3	1.3	1.3	1.1
2.0	2.2	2.2	2.2	2.0	1.8	1.5	1.5	1.4	1.4	1.3	1.3
2.5	2.2	2.2	2.2	2.2	2.0	1.8	1.7	1.5	1.4	1.4	1.3
3.0	2.2	2.2	2.2	2.2	2.2	2.2	1.8	1.7	1.5	1.5	1.4
3.5	2.2	2.2	2.2	2.2	2.2	2.2	1.9	1.8	1.7	1.5	1.4
4.0	2.2	2.2	2.2	2.2	2.2	2.2	2.1	1.9	1.8	1.7	1.5
4.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9	1.8	1.7
5.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9	1.8
5.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.0	1.9
6.0	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.1	2.0
6.5	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2

Note: For pipe diameters other than listed,  $B_{fLL}$  values can be obtained by interpolation.

#### 17.4.5.1.1 Ultimate D-load

The required D-load at which the pipe develops its ultimate strength in a three-edge-bearing test is the design D-load (at 0.01-inch crack) multiplied by a strength factor that is specified in AASHTO materials specifications M 170 or M 242 (ASTM C 76 or C 655) for Circular pipe, M 206 (ASTM C 506) for Arch Pipe and M 207 (ASTM C 507) for Elliptical Pipe.

#### 17.4.5.2 Bedding Factor

The bedding factor,  $B_f$ , is the ratio of the supporting strength of buried pipe to the strength of the pipe determined in the three-edge-bearing test. The supporting strength of buried pipe depends on the type of Standard Installation. See figures 17.4B and 17.4C for circular pipe and figures 17.4D and 17.4E for other arch and elliptical shapes. Table 17.4A applies to circular, arch and elliptical shapes.

##### 17.4.5.2.1 Earth Load Bedding Factor for Circular Pipe

Earth load bedding factors,  $B_{fe}$ , for circular pipe are presented in Table 17.4C.

##### 17.4.5.2.2 Earth Load Bedding Factor for Arch and Elliptical Pipe

The bedding factor for installations of arch and elliptical pipe, Figures 17.4D and 17.4E, is:

$$B_{fe} = \frac{C_A}{C_N - xq} \quad (17-3)$$

Values for  $C_A$  and  $C_N$  are listed in Table 17.4B.

$C_A$  = a constant corresponding to the shape of the pipe;

$C_N$  = a parameter which is a function of the distribution of the vertical load and vertical reaction;

$x$  = a parameter which is a function of the area of the vertical projection of the pipe over which lateral pressure is effective;

$q$  = the ratio of the total lateral pressure to the total vertical fill load. Design values for  $C_A$ ,  $C_N$ , and  $x$  are found in Table 17.4B. The value of  $q$  is determined by the following equations:

Arch and Horizontal Elliptical Pipe:

$$q = .23 \frac{P}{F_e} \left( 1 + .35p \frac{B_c}{H} \right) \quad (17-4)$$

Vertical Elliptical Pipe:

$$q = .48 \frac{P}{F_e} \left( 1 + .73p \frac{B_c}{H} \right) \quad (17-5)$$

where:

$p$  = projection ratio, ratio of the vertical distance between the outside top of the pipe and the ground or bedding surface to the outside vertical height of the pipe;

#### 17.4.5.2.3 Live Load Bedding Factor

The bedding factors for live load,  $W_L$ , for both Circular pipe and Arch and Elliptical pipe are given in Table 17.4D. If  $B_{fe}$  is less than  $B_{fLL}$  use  $B_{fe}$  instead of  $B_{fLL}$  for the live load bedding factor.

#### 17.4.5.2.4 Intermediate Trench Widths

For intermediate trench widths, the bedding factor may be estimated by interpolation between the narrow trench and transition width bedding factors.

### 17.4.6 Direct Design Method for Precast Reinforced Concrete Circular Pipe

#### 17.4.6.1 Application

This Specification is intended for use in direct design of precast reinforced concrete pipe and is based on design of pipe wall for effects of loads and pressure distribution for installed conditions. Standard dimensions are shown in AASHTO Material Specification M170. Design wall thicknesses other than the standard wall dimension may be used provided the design complies with all applicable requirements of Section 17.

#### 17.4.6.2 General

Design shall conform to applicable sections of these specifications, except as provided otherwise in this section.

The total load on the pipe shall be determined according to Article 17.4.4 and Table 3.22.1A.

The pressure distribution on the pipe from applied loads and bedding reaction shall be determined from a soil-structure analysis or shall be a rational approximation. Acceptable pressure distribution diagrams are the Heger Pressure Distribution (see Figure 17.4A) for use with the Standard Installations; the Olander/Modified Olander Radial Pressure Distribution (see Figure 17.4 F(a) or the Paris/Manual Uniform Pressure Distribution (see Figure 17.4 F(b)). For bedding angles and lateral pressures used with the latter distributions see Figure 17H through Figure 17J.

For use with the Heger Pressure Distribution, three Types of Standard Embankment installations, soil types, and compaction requirements are depicted in Figures 17.4B through 17.4E and Table 17.4A.

Other methods for determining total load and pressure distribution may be used, if based on successful design practice or tests that reflect the appropriate design condition.

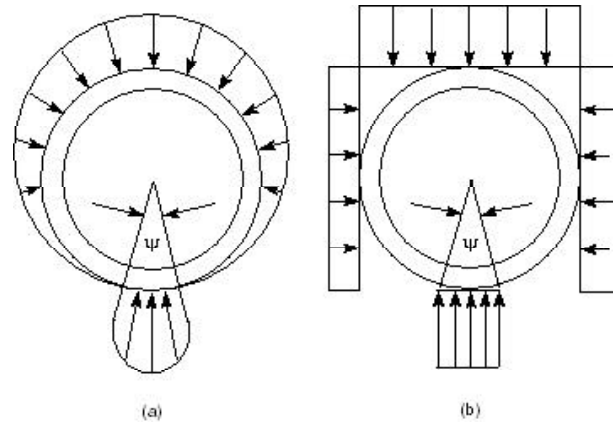
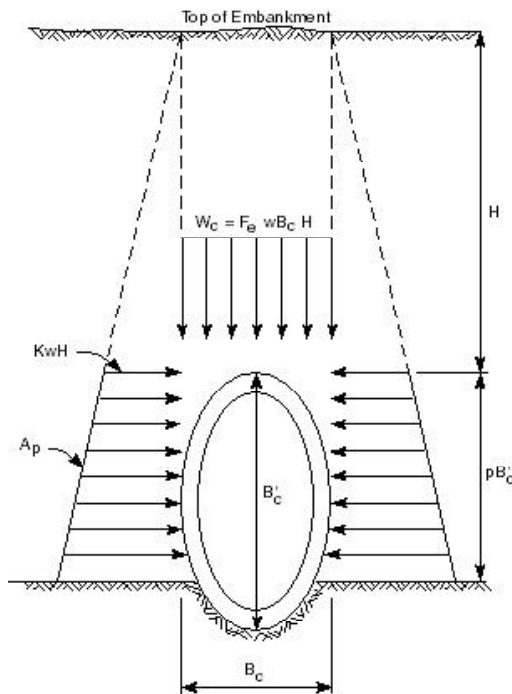


Figure 17.4F



**Figure 17.4G General Relationship of Vertical Earth Load and Lateral Pressure**

### 17.4.6.3 Strength-Reduction Factors

Strength-reduction factors for load factor design of plant made reinforced concrete pipe may be taken as 1.0 for flexure ( $f_f$ ) and 0.9 for shear ( $f_v$ ) and radial tension ( $f_r$ ). For type 1 installations, the strength-reduction factor shall be 0.9 for flexure and 0.82 for shear and radial tension.

### 17.4.6.4 Process and Material Factors

Process and material factors,  $F_{rp}$  for radial tension and  $F_{vp}$  for shear strength for load factor design of plant made reinforced concrete pipe are conservatively taken as 1.0. Higher values may be used if substantiated by appropriate test data approved by the Engineer.

### 17.4.6.5 Orientation Angle

When quadrant mats, stirrups and/or elliptical cages are used, the pipe installation requires a specific orientation. Designs shall be based on the possibility of a rotation misorientation during installation by an Orientation Angle of 10 degrees in either direction.

### 17.4.6.6 Reinforcement

#### 17.4.6.6.1 Reinforcement for Flexural Strength

$$A_s = \left( g f_f d - N_U - \sqrt{g [g (f_f d)^2 - N_U (2 f_f d - h) - 2 M_U]} \right) \frac{1}{f_y} \quad (17-6)$$

$$\text{where } g = 0.85 b f'_c \\ b = 12 \text{ in.}$$

#### 17.4.6.6.2 Minimum Reinforcement

For inside face of pipe:

$$A_{si} = \frac{b}{12} (S_i + h)^2 / (f_y) \quad (17-7)$$

where  $b = 12 \text{ in.}$

For outside face of pipe:

$$A_{so} = 0.60 \left( \frac{b}{12} \right) (S_i + h)^2 / (f_y) \quad (17-8)$$

where  $b = 12 \text{ in.}$

For elliptical reinforcement in circular pipe and for pipe 33-inch diameter and smaller with a single cage of reinforcement in the middle third of the pipe wall, reinforcement shall not be less than  $A_s$ , where:

$$A_s = 2 \left( \frac{b}{12} \right) (S_i + h)^2 / (f_y) \quad (17-9)$$

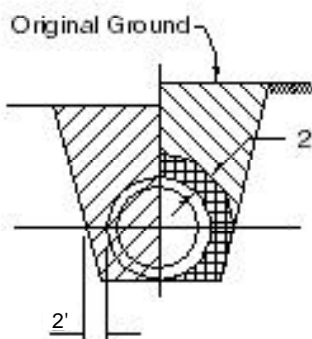
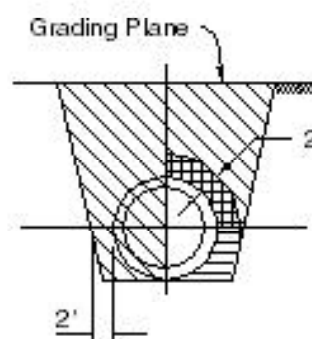
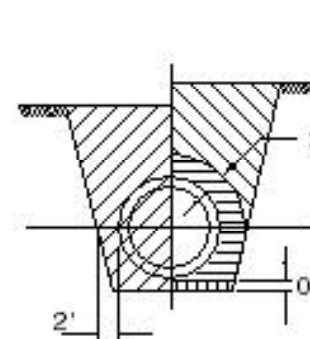
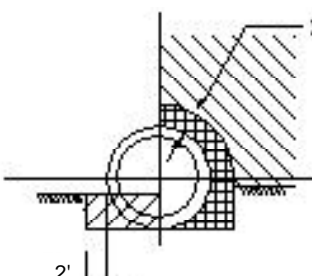
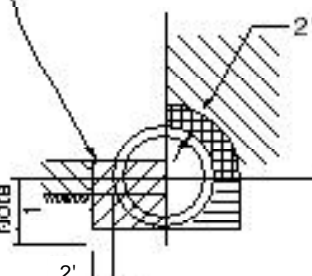
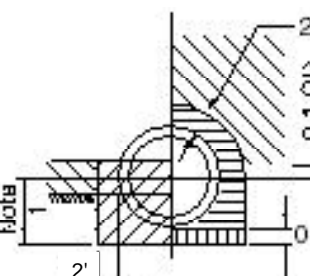
where  $b = 12 \text{ in.}$

where:

$h$  = wall thickness in inches;

$S_i$  = internal diameter or horizontal span of pipe in inches.

In no case shall the minimum reinforcement be less than 0.07 square inches per linear foot.

Walls A & B			
	Method 1	Method 2	Method 3 a
Trench	EXCAVATION BACKFILL 	EXCAVATION BACKFILL 	EXCAVATION BACKFILL 
Embankment		Embankment constructed prior to excavation 	
Bedding Angle	60°	90°	120°

### Legend



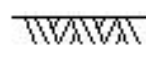
Structure Excavation (Culvert)



Roadway Embankment



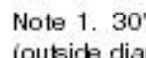
Structure Backfill (Culvert)  
95% relative compaction



Original Ground



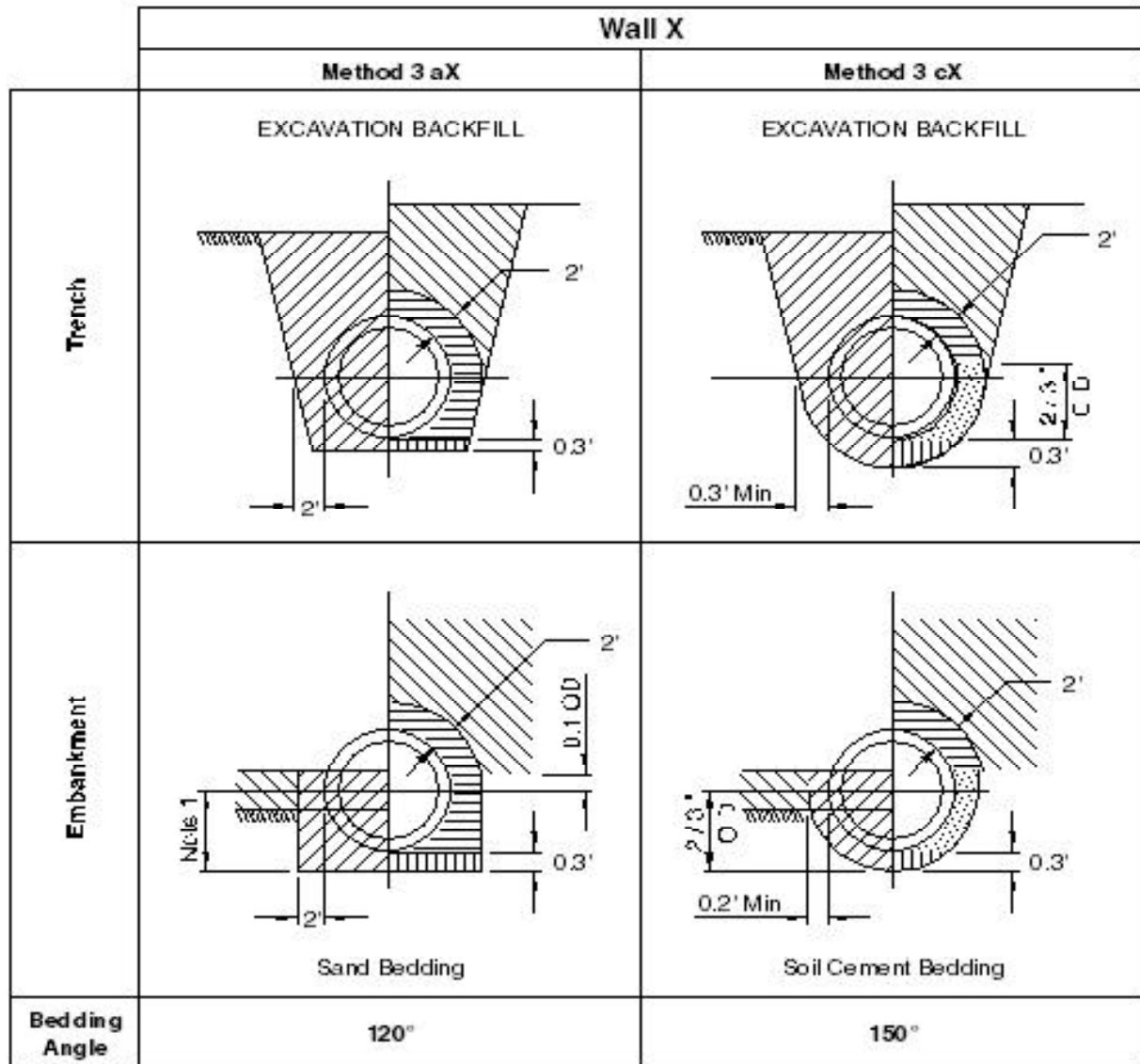
Structure Backfill (Culvert)  
90% relative compaction



Sand Bedding

Note 1. 30° minimum up to 45° OD, then  $\frac{2}{3}$  OD (outside diameter) but no more than 60° required.

Figure 17.4H



### Legend



Note 1. 30" minimum up to 45" OD, than  $\frac{2}{3}$  OD (outside diameter) but no more than 60" required.

Figure 17.4I

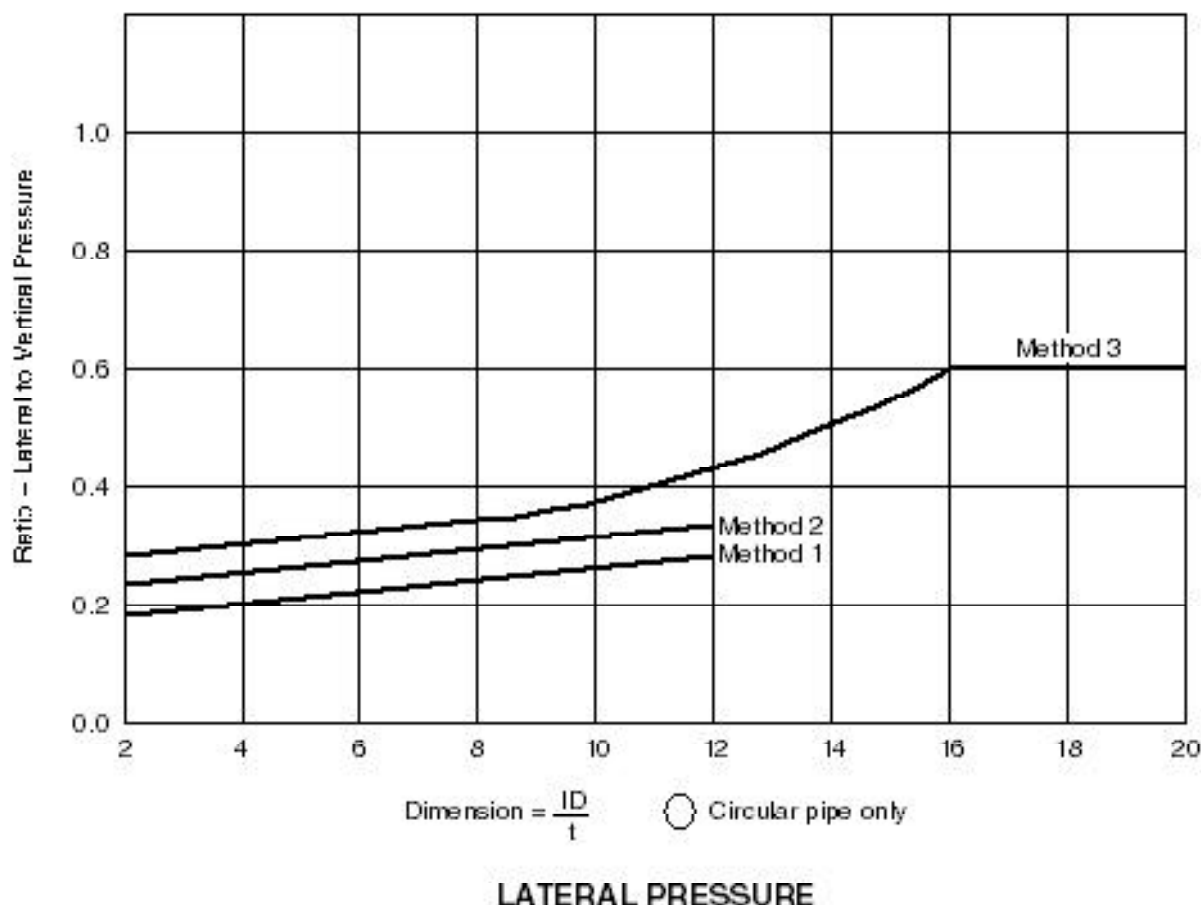


Figure 17.4J

### 17.4.6.6.3 Maximum Flexural Reinforcement Without Stirrups

#### 17.4.6.6.3.1 Limited by Radial Tension

$$\text{Inside } A_{s \max} = \left( \frac{b}{12} \right) \left( 16 r_s F_{rp} \sqrt{f'_c} \left( \frac{f_r}{f_f} \right) F_{rt} \right) / (f_y) \quad (17-10)$$

$A_{s \max}$  = maximum flexural reinforcement area with out stirrups  $\text{in.}^2/\text{ft}$  where  $b = 12 \text{ in.}$

$$F_{rt} = 1 + 0.00833 (72 - S_i) \quad \text{For } 12 \text{ in} \leq S_i \leq 72 \text{ in.}$$

$$F_{rp} = 1.0 \text{ unless a higher value substantiated by test data is approved by the Engineer;}$$

$$F_{rt} = \frac{(144 - S_i)^2}{26,000} + 0.80$$

For  $72 \text{ in.} < S_i = 144 \text{ in.}$

$$F_{rt} = 0.8 \text{ for } S_i > 144 \text{ in.}$$

$$r_s = \text{radius of the inside reinforcement in inches.}$$

#### 17.4.6.6.3.2 Limited by Concrete Compression

$$A_{s \max} = \left( \left[ \frac{5.5 \times 10^4 g' f_f d}{87,000 + f_y} \right] - 0.75 N_U \right) / (f_y) \quad (17-11)$$



where:

$$g' = bf'_c \left[ 0.85 - 0.05 \frac{(f'_c - 4,000)}{1,000} \right]$$

$$g' = 0.85 bf'_c \text{ and } g'_{\min} = 0.65 bf'_c$$

#### 17.4.6.6.4 Crack Width Control (Service Load Design)

$$F_{cr} = \frac{B_1}{30,000 f_f d A_s} \left[ \frac{M_s + N_s \left( d - \frac{h}{2} \right)}{ij} - C_1 b h^2 \sqrt{f'_c} \right] \quad (17-12)$$

+ Cover for crack control analysis is assumed to be 1 in.  
+ over the tension reinforcement, even if it is greater or less  
+ than 1 in. The crack control factor  $F_{cr}$  in equation 17-12 indicates the probability that a crack of a specified maximum width will occur.

When  $F_{cr} = 1.0$ , the reinforcement area,  $A_s$ , will produce an average crack maximum width of 0.01 inch. For  $F_{cr}$  values less than 1.0, the probability of a 0.01 inch crack is reduced. For  $F_{cr}$  values greater than 1.0, the probability of a crack greater than 0.01 inch is increased.

where:

$F_{cr}$  = crack control factor

$M_s$  = bending moment, service load;

$N_s$  = thrust (positive when compressive), service load.

If the service load thrust,  $N_s$ , is tensile rather than compressive (this may occur in pipes subject to intermittent hydrostatic pressure), use the quantity  $(1.1M_s - 0.6N_s d)$  (with tensile  $N_s$  taken negative) in place of the quantity  $([M_s + N_s(d - h/2)]/ji)$  in Equation (17-12).

$$j \cong 0.74 + 0.1e/d;$$

$$j_{\max} = 0.9;$$

$$i = \frac{1}{1 - \frac{jd}{e}}$$

$$e = \frac{M_s}{N_s} + d - \frac{h}{2}, \text{ in.}$$

if  $e/d < 1.15$  crack control will not govern.

$t_b$  = clear cover over reinforcement in inches

$h$  = wall thickness of pipe in inches;

$$B_1 = \sqrt[3]{t_b s_\ell / 2n}$$

where:

$s_\ell$  = spacing of circumferential reinforcement, in.

$n$  = 1, when tension reinforcement is a single layer.

$n$  = 2, when tension reinforcement is made of multiple layers.

#### $C_1$ = Crack Control Coefficient

Type of Reinforcement:	$C_1$
1. Smooth wire or plain bars	1.0
2. Welded smooth wire fabric, 8in. (200mm) maximum spacing of longitudinals	1.5
3. Welded deformed wire fabric, deformed wire, deformed bars or any reinforcement with stirrups anchored thereto.	1.9

Notes: Higher values for  $C_1$  may be used if substantiated by test data and approved by the Engineer.

#### 17.4.6.6.5 Shear Strength

The area of reinforcement,  $A_s$ , determined in Article 17.4.6.6.1 or 17.4.6.6.4 must be checked for shear strength adequacy, so that the basic shear strength,  $V_b$ , is greater than the factored shear force,  $V_{uc}$ , at the critical section located where  $M_{nu}/V_{ud} = 3.0$ .

$$V_b = b f_v d F_{vp} \sqrt{f'_c} (1.1 + 63r) \left[ \frac{F_d F_N}{F_c} \right] \quad (17-13)$$

where

$V_b$  = shear strength of section where  $M_{nu}/V_{ud} = 3.0$ ;

$F_{vp}$  = 1.0 unless a higher value substantiated by test data is approved by the Engineer;

$$r = \frac{A_s}{bd}$$

$$r_{\max} = 0.02;$$

$$f'_{c \max} = 7,000 \text{ psi};$$

$$F_d = 0.8 + \frac{1.6}{d}$$

max  $F_d$  = 1.3 for pipe with two cages, or a single elliptical cage

max  $F_d$  = 1.4 for pipe through 36-inch diameter with a single circular cage

$$F_c = 1 \pm \frac{d}{2r}$$

(+) tension on the inside of the pipe

(-) tension on the outside of the pipe

For compressive thrust (+  $N_u$ ):

$$F_N = 1 + \frac{N_U}{2,000bh}$$

where  $b = 12$  in.

For tensile thrust (-  $N_u$ ):

$$F_N = 1 + \frac{N_U}{500bh}$$

where  $b = 12$  in.

$$M_{nu} = M_u - N_u$$

If  $V_b$  is less than  $V_{uc}$ , radial stirrups must be provided. See Article 17.4.6.6.6.

#### 17.4.6.6.6 Radial Stirrups

##### 17.4.6.6.6.1 Radial Tension Stirrups

$$A_{vr} = \frac{1.1s_v(M_u - 0.45N_u f_r d)}{f_v f_s f_r d} \quad (17-14)$$

where:

$A_{vr}$  = required area of stirrup reinforcement for radial tension;

$s_v$  = circumferential spacing of stirrups ( $s_{v \max} = 0.75\phi_v d$ );

$f_v$  = maximum allowable strength of stirrup material ( $f_{\max} = f_y$ , or anchorage strength whichever is less).

#### 17.4.6.6.6.2 Shear Stirrups

$$A_{vs} = \frac{1.1s_v}{f_{vs} f_v d} [V_u F_c - V_c] \quad (17-15)$$

where:

$A_{vs}$  = required area of stirrups for shear reinforcement;

$V_u$  = factored shear force at section;

$$V_c = \frac{4V_b}{\frac{M_{nu}}{V_u d} + 1}$$

$$V_{c \max} = 2f_v b d \sqrt{f'_c}$$

$$S_{v \max} = 0.75f_v d$$

$f_{v \max}$  =  $f_y$  or anchorage strength, whichever is less

A conservative approximation of the total required stirrup area is:

$$A_v = A_{vs} + A_{vr}$$

#### 17.4.6.6.6.3 Stirrup Reinforcement Anchorage

##### 17.4.6.6.6.3.1 Radial Tension Stirrup Anchorage

When stirrups are used to resist radial tension, they shall be anchored around each circumferential of the inside cage to develop the design strength of the stirrup, and they shall also be anchored around the outside cage, or embedded sufficiently in the compression side to develop the design strength of the stirrup.

##### 17.4.6.6.6.3.2 Shear Stirrup Anchorage

When stirrups are not required for radial tension but required for shear, their longitudinal spacing shall be such that they are anchored around each or every other tension circumferential. Such spacings shall not exceed 6 inches (150 mm).

### 17.4.6.6.3.3 *Stirrup Embedment*

Stirrups intended to resist forces in the invert and crown regions shall be anchored sufficiently in the opposite side of the pipe wall to develop the design strength of the stirrup.

### 17.4.6.6.3.4 *Other Provisions*

Section 8.27, Development of Shear Reinforcement, does not apply to pipe designed according to provisions of Section 17.4.5.

## 17.4.7 Development of Quadrant Mat Reinforcement

**17.4.7.1** When the quadrant mat reinforcement is used, the area of the continuous main cages shall be no less than 25% of the area required at the point of maximum moment.

**17.4.7.2** In lieu of 17.4.7.1, a more detailed analysis may be made.

**17.4.7.2.1** For quadrant mat reinforcement consisting of welded smooth wire fabric, the outermost longitudinals on each end of the circumferentials shall be embedded: (a) past the point where the quadrant reinforcement is no longer required by the orientation angle plus the greater of 12 circumferential wire diameters or  $\frac{3}{4}$  of the wall thickness of the pipe, and (b) past the point of maximum flexural stress by the orientation angle plus the development length,  $L_d$ .

$$L_d = 0.27 \frac{A_{wr} f_y}{s \sqrt{f'_c}} \quad (17-16)$$

but not less than :

$$L_d = s_\ell + 1$$

The mat shall contain no less than 2 longitudinals at a distance one inch greater than that determined by the orientation angle from either side of the point requiring the maximum flexural reinforcement.

The point of embedment of the outermost longitudinals of the mat shall be at least a distance determined by the orientation angle past the point where the continuing reinforcement is no less than the double area required for flexure.

**17.4.7.2.2** For quadrant mat reinforcement consisting of deformed bars, deformed wire, or welded wire fabric (a) circumferentials shall extend past the point where they are no longer required by the orientation angle plus the greater of 12 wire diameters or  $\frac{3}{4}$  of the wall thickness of the pipe. (b) The circumferentials shall extend on either side of the point of maximum flexural stress not less than the orientation angle plus the development length  $L_d$  required by equation 17-17 and (c) they shall extend at least a distance determined by the orientation angle past the point where the continuing reinforcement is no less than double the area required by flexure.

$$L_d = \frac{0.03 d_b f_y A_{wr}}{A_{wa} \sqrt{f'_c}} \quad (17-17)$$

but not less than:

$$L_d = 0.015 d_b \frac{f_y}{\sqrt{f'_c}}$$

## 17.5 REINFORCED CONCRETE ARCH, CAST-IN-PLACE

### 17.5.1 Application

This specification is intended for use in the design of cast-in-place reinforced concrete arches with the arch barrel monolithic with each footing. A separate reinforced concrete invert may be required where the structure is subject to scour.

### 17.5.2 Materials

#### 17.5.2.1 Concrete

Concrete shall conform to Article 8.2.

#### 17.5.2.2 Reinforcement

Reinforcement shall meet the requirements of Article 8.3.

### 17.5.3 Design

#### 17.5.3.1 General Requirements

Design shall conform to these specifications except as provided otherwise in this Section. For design loads and loading conditions, see Article 3.2 and Section 6. For reinforced concrete design requirements see Section 8.

#### 17.5.3.2 Minimum Cover

The minimum fill over reinforced concrete arches shall be 2 feet or Span /8.

#### 17.5.3.3 Strength-Reduction Factors

Strength reduction factors for load factor design of cast-in-place arches may be taken as 0.90 for flexure and 0.85 for shear.

#### 17.5.3.4 Splices of Reinforcement

Reinforcement shall be in conformity with Article 8.32. If lap splicing is used, laps shall be staggered with a minimum of one foot measured along the circumference of the arch. Ties shall be provided connecting the intrados and extrados reinforcement. Ties shall be at 12-inch maximum spacing, in both longitudinal and circumferential directions, except as modified by shear.

#### 17.5.3.5 Footing Design

Design shall include consideration of differential horizontal and vertical movements and footing rotations. Footing design shall conform to Article 4.4.

## 17.6 REINFORCED CONCRETE BOX, CAST-IN-PLACE

### 17.6.1 Application

The specification is intended for use in the design of cast-in-place reinforced concrete box culverts.

### 17.6.2 Materials

#### 17.6.2.1 Concrete

Concrete shall conform to Article 8.2 except that evaluation of  $f'_c$  may be based on test beams.

#### 17.6.2.2 Reinforcement

Reinforcement shall meet the requirements of Article 8.3 except that for welded wire fabric a yield strength of 65,000 psi may be used. For wire fabric, the spacing of longitudinal wires shall be a maximum of 8 inches.

### 17.6.3 Concrete Cover for Reinforcement

The minimum concrete cover for reinforcement shall conform to Article 8.22. The top slab shall be considered a bridge slab for concrete cover considerations.

### 17.6.4 Design

#### 17.6.4.1 General Requirements

Designs shall conform to applicable sections of these specifications except as provided otherwise in this section. For design loads and loading conditions see Section 3. For distribution of concentrated loads through earth for culverts with 2 feet or less of cover see Article 3.24.3, Case B, and for requirements for bottom distribution reinforcement in top slabs of such culverts see Article 3.24.10. For distribution of wheel loads to culverts with more than 2 feet of cover see Article 6.5. For reinforced concrete design requirements see Section 8.

#### 17.6.4.2 Deleted

#### 17.6.4.3 Distribution of Concentrated Load Effects to Bottom Slab

Concentrated wheel loads may be distributed over the full width of the bottom slab transversely and over 7' longitudinally.

#### 17.6.4.4 Distribution of Concentrated Loads in Skewed Culverts

Wheel loads on skewed culverts shall be distributed using the same provisions as given for culverts with main reinforcement parallel to traffic.

#### 17.6.4.5 Span Length

For span length see Article 8.8, except when monolithic haunches included at 45 degrees are considered in the design, negative moment reinforcement in walls and slabs may be proportioned based on the bending moment where the depth of the haunch equals 1.5 times the thickness of the member.

#### 17.6.4.6 Strength Reduction Factors

Strength reduction factors for load factor design may be taken as 0.9 for combined flexure and thrust and as 0.85 shear.

#### 17.6.4.7 Crack Control

The service load stress should be computed considering the effects of both bending moment and thrust using:

$$f_{ss} = \frac{M_s + N_s \left( d - \frac{h}{2} \right)}{(A_s j d)} \quad (17-18)$$

where:

- $f_{ss}$  = stress in reinforcement under service load conditions, psi
- $e$  =  $M_s/N_s + d - h/2$
- $e/d$  min. = 1.15
- $i$  =  $1/(1 - (jd/e))$
- $j$  =  $0.74 + 0.1 (e/d) \leq 0.9$

The maximum allowable service load stress in the reinforcing steel for crack control shall be:

$$f_s = \frac{155}{\beta \sqrt[3]{d_c A}} \leq 0.6 f_y \text{ ksi} \quad (17-19)$$

$$b = \left[ 1 + \frac{d_c}{0.7d} \right]$$

$b$  = approximate ratio of distance from the neutral axis to the location of the crack width at the concrete surface divided by the distance from the neutral axis to the centroid of tensile reinforcing.

$d_c$  = distance measured from the extreme tension fiber to the center of the closest bar or wire in inches. For

calculation purposes, the thickness of clear concrete cover used to compute  $d_c$  shall not be taken greater than 2 inches.

#### 17.6.4.8 Minimum Reinforcement

Minimum reinforcement shall be provided in accordance with Article 8.17.1 at all cross sections subject to flexural tension, including the inside face of walls. Shrinkage and temperature reinforcement shall be provided near the inside surfaces of walls and slabs in accordance with Article 8.20.

### 17.7 REINFORCED CONCRETE BOX, PRECAST

#### 17.7.1 Application

This specification is intended for use in design of precast reinforced concrete box sections. Boxes may be manufactured using conventional structural concrete and forms (formed) or with dry concrete and vibrating form pipe making methods (machine-made). Standard dimensions are shown in AASHTO Materials Specification M 259, and M 273.

#### 17.7.2 Materials

##### 17.7.2.1 Concrete

Concrete shall conform to Article 8.2 except that evaluation of  $f'_c$  may be based on cores.

##### 17.7.2.2 Reinforcement

Reinforcement shall meet the requirements of Article 8.3 except that for welded wire fabric a yield strength of 65,000 psi may be used. For wire fabric, the spacing of longitudinal wires shall be a maximum of 8 inches.

#### 17.7.3 Concrete Cover for Reinforcement

The minimum design concrete cover for reinforcement in boxes reinforced with wire fabric shall be 1 inch.

## 17.7.4 Design

### 17.7.4.1 General Requirements

Design shall conform to applicable sections of these specifications except as provided otherwise in this Section. For design loads and loading conditions see Section 3. For distribution of wheel loads to culvert slabs with 2 feet or less of cover see Article 3.24.3, Case B, and for requirements for bottom reinforcement in top slabs of such culverts see Article 3.24.10. For distribution of wheel loads to culvert slabs with more than 2 feet of cover, see Article 6.4.

For reinforced concrete design requirements see Section 8. For span length see Article 8.8, except as noted in Article 17.7.4.5.

### 17.7.4.2 Deleted

### 17.7.4.3 Distribution of Concentrated Load Effects in Sides and Bottoms

The width of the top slab strip used for distribution of concentrated wheel loads shall also be used for determination of bending moments, shears and thrusts in the sides and bottom.

### 17.7.4.4 Distribution of Concentrated Loads in Skewed Culverts

Wheel loads on skewed culverts shall be distributed using the same provisions as given for culverts with main reinforcement parallel to traffic.

### 17.7.4.5 Span Length

When monolithic haunches inclined at 45 degrees are taken into account, negative reinforcement in walls and slabs may be proportioned based on the bending moment where the depth of the haunch equals 1.5 times the thickness of the member.

### 17.7.4.6 Strength Reduction Factors

Strength reduction factors for load factor design of machine-made boxes may be taken as 1.0 for moment and 0.9 for shear.

### 17.7.4.7 Crack Control

The service load stress should be computed considering the effects of both bending moment and thrust using:

$$f_{ss} = \frac{M_s + N_s \left( d - \frac{h}{2} \right)}{(A_s j i d)} \quad (17-20)$$

where:

$f_{ss}$  = stress in reinforcement under service load conditions, psi

$e$  =  $M_s/N_s + d - h/2$

$e/d_{min.}$  = 1.15

$i$  =  $1/(1 - (j d/e))$

$j$  =  $0.74 + 0.1 (e/d) \leq 0.9$

The maximum service load stress in the reinforcing steel for crack control shall be:

$$f_s = \frac{98}{\sqrt[3]{d_c A}} \text{ ksi} \quad (17-21)$$

### 17.7.4.8 Minimum Reinforcement

The primary flexural reinforcement in the direction of the span shall provide a ratio of reinforcement area to gross concrete area at least equal to 0.002. Such minimum reinforcement shall be provided at all cross sections subject to flexural tension, at the inside face of walls, and in each direction at the top of slabs of box sections with less than 2 feet of fill. The provisions of Article 8.20 do not apply to precast concrete box sections, except if units of unusual length (over 16 ft.) are fabricated, the minimum longitudinal reinforcement for shrinkage and temperature should be as provided in Article 8.20.

### 17.7.4.9 Shear Transfer in Transverse Joints Between Culvert Sections

For boxes with less than 2 feet of cover, the top slab joint shall either conform to the edge beam requirements of Article 3.24.8, or be capable of transferring a minimum shear load of 3,000 pounds per linear foot of top slab joint.

- + If individual shear connectors are used, they shall be
- + spaced at no more than 2.5 feet on center with a minimum
- + of 2 connectors per joint.

## 17.8 PRECAST REINFORCED CONCRETE THREE-SIDED STRUCTURES

### 17.8.1 Application

This specification is intended for use in design of precast reinforced concrete three-sided structures supported on a concrete footing foundation. Units may be manufactured using conventional structural concrete and forms (formed) or machine made using low slump concrete and vibrating forms.

### 17.8.2 Materials

#### 17.8.2.1 Concrete

Concrete shall conform to Article 8.2 except that evaluation of  $f'_c$  may also be based on cores.

#### 17.8.2.2 Reinforcement

Reinforcement shall meet the requirements of Article 8.3 except that for welded wire fabric a yield strength of 65,000 psi may be used. For wire fabric, the spacing of longitudinal wires shall be a maximum of 8 inches. Circumferential welded wire fabric spacing shall not exceed a 4-inch maximum and a 2-inch minimum. Prestressing if used, shall be in accordance with Section 9.

### 17.8.3 Concrete Cover for Reinforcement

- + The minimum concrete cover for reinforcement in precast three-sided structures reinforced with welded wire fabric shall be 1 inch.

### 17.8.4 Geometric Properties

The shape of the precast three-sided structures may vary in span, rise, wall thickness, haunch dimensions and curvature. Specific geometric properties shall be specified by the manufacturer. Wall thicknesses, however, shall be a minimum of 8 inches for spans under 24 feet and 10 inches for 24-foot spans and larger.

## 17.8.5 Design

### 17.8.5.1 General Requirements

Designs shall conform to applicable Sections of these specifications except as provided otherwise in this Section. For design loads and loading conditions see Section 3. For distribution of wheel loads to culvert surfaces under 2 feet and less of cover see Article 3.24.3, Case B. For requirements for bottom reinforcement in top slabs of such culverts see Article 3.24.10. For distribution of wheel loads to culvert surfaces with more than 2 feet of cover, see Article 6.5.

For reinforced concrete design requirements see Section 8 and for prestress concrete design requirements see Section 9. For span length see Article 8.8, except as noted in Article 17.8.5.5. Design analysis shall be based on a pinned (hinged) connection at the footing and take into account footing movement, see Article 17.8.5.10.

### 17.8.5.2 Distribution of Concentrated Load Effects in Side

The width of the top slab strip used for distribution of concentrated wheel loads shall also be used for determination of bending moments, shears and thrusts in the sides.

### 17.8.5.3 Distribution of Concentrated Loads in Skewed Culverts

Wheel loads on skewed culverts shall be distributed using the same provisions as given for culverts with main reinforcement parallel to traffic. For culvert elements with skews greater than 15°, the effect of the skew shall be considered in analysis.

### 17.8.5.4 Shear Transfer in Transverse Joints Between Culvert Section

Each precast three-sided structure is analyzed independently with no shear or stress transfer assumed between sections. As no shear transfer is assumed between sections, distribution width for a wheel load must be limited to the unit width. For structures with 2 feet and less of cover, the top slab shall conform to the edge beam requirements of Article 3.24.8 unless it is designed by a finite element method in which case the moment applied to the one foot edge section shall be 60% greater than that

+ calculated. Flat top structures with shallow cover may experience differential deflection of adjacent units which can cause pavement cracking if a shear key is not utilized.

#### 17.8.5.5 Span Length

When monolithic haunches inclined at 45 degrees are taken into account, negative reinforcement in walls and slabs may be proportioned based on the bending moment where the depth of the haunch equals 1.5 times the thickness of the member.

#### 17.8.5.6 Strength Reduction Factor

These structures shall be designed by load factor design and the maximum strength reduction factors shall be 0.95 for combined flexure and thrust and 0.9 for shear. See Section 8 and Section 9 for factors used for cast-in-place and prestressed components, respectively.

#### 17.8.5.7 Crack Control

The service load stress should be computed considering the effects of both bending moment and thrust using:

$$f_{ss} = \frac{M_s + N_s \left( d - \frac{h}{2} \right)}{(A_s j d)} \quad (17-22)$$

where:

$f_{ss}$  = stress in reinforcement under service load conditions, psi

$e$  =  $M_s / N_s + d - h/2$

$e/d \text{ min.} = 1.15$

$i$  =  $1 / (1 - (j d / e))$

$j$  =  $0.74 + 0.1 (e/d) \leq 0.9$

The maximum service load stress in the reinforcing steel for crack control shall be:

$$f_s = \frac{98 \text{ ksi}}{\sqrt[3]{d_c A}} \quad (17-23)$$

#### 17.8.5.8 Minimum Reinforcement

The primary flexural reinforcement in the direction of the span shall provide a ratio of reinforcement area to gross concrete area at least equal to 0.002. Such minimum reinforcement shall be provided at all cross sections subject to flexural tension, at the inside face of walls, and in each direction at the top of slabs of three-sided sections with 2 feet and less of fill. The provisions of Article 8.20 do not apply to precast three-sided structures.

#### 17.8.5.9 Deflection Control

Live load deflection of the top section in three-sided structures shall not exceed  $1/800$  of the span, except for sections in urban areas used in part by pedestrians, the ratio shall not exceed  $1/1000$ .

#### 17.8.5.10 Footing Design

Design shall include consideration of differential horizontal and vertical movements and footing rotations. Footing design shall conform to Article 4.4.

#### 17.8.5.11 Structure Backfill

Different backfill may be required depending on design assumptions. However, a minimum backfill compaction requirement of 90% relative compaction should be achieved to prevent roadway settlement adjacent to the structure. A higher backfill compaction density may be required on structures utilizing a soil-structure interaction system.

#### 17.8.5.12 Scour Protection

Consideration should be given to scour susceptibility. Footing protection should be designed accordingly.